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The health, financial and environmental impacts of unnecessary vitamin D testing: a triple bottom line assessment

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ABSTRACT

Objective: To undertake an assessment of the health, financial, and environmental impacts (triple bottom line) of a well-recognised example of low value care; inappropriate vitamin D testing.

Design: Combination of systematic literature search, analysis of routinely collected healthcare data and environmental analysis.

Setting: Australian healthcare system.

Participants: Population of Australia.

Outcome measures: We took a sustainability approach, measuring triple bottom line (health, financial, environmental) impacts. Inappropriate (unnecessary) vitamin D testing rates were estimated from best available published literature; by definition, these provide no gain in health outcomes (in contrast to appropriate/necessary tests). Australian population-based test numbers and healthcare costs were obtained from Medicare for vitamin D pathology services. Carbon emissions in kg CO_2e were estimated using data from our previous study of the carbon footprint of common pathology tests. We distinguished between tests ordered as the primary test and those ordered as an add-on to other tests, as many may be done in conjunction with other tests. We conducted base case (8% being the primary reason for the blood test) and sensitivity (12% primary test) analyses.

Results: There was a total of 4,457,657 Medicare funded vitamin D tests in 2020, on average one test for every six Australians, an 11.8% increase from the mean 2018-2019 total. From our literature review, 76.5% of Australia's vitamin D tests are unnecessary, equating to 3,410,108 unnecessary tests in 2020. Total costs of unnecessary tests to Medicare amounted to >$87,000,000AUD. The 2020 carbon footprint of unnecessary vitamin D tests was 28,576kg (base case) and 42,012kg (sensitivity) CO_2e, equivalent to driving ~160,000–230,000km in a standard passenger car.

Conclusions: Unnecessary vitamin D testing contributes to avoidable CO_2e emissions and healthcare costs. While the footprint of this example is relatively small, the potential to realise environmental co-benefits by reducing low value care more broadly is significant.

Strengths and limitations of this study

Strengths:

- To our knowledge, this is the first study to undertake a triple bottom line assessment of a low value healthcare activity to explore and make explicit its health, financial and environmental impacts.
- Our triple bottom line assessment of vitamin D testing highlights that low value care, which provides little or no gain in health outcomes, adds significant financial costs, and contributes avoidable CO_2e emissions.
- Reducing low value care is an opportunity to reduce carbon emissions and expenditure on healthcare without adversely affecting quality of care or patient outcomes; this is an important consideration in achieving healthcare sustainability.

Limitations of this study:

- Unnecessary tests or inappropriate testing is a surrogate measure of health impact, rather than a direct measure. Yet there is global acceptance that unnecessary vitamin D testing (which varies widely from 37% to 92% in different jurisdictions) provides no, or at most negligible, health benefit.
- Our estimate of carbon emissions is specific to Australia and may vary in other countries depending on local electricity sources and supply chains. Other environmental impacts, such as emissions of PM2.5 which contribute to air pollution, have not been included in our analysis.

Introduction

Healthcare has a significant carbon footprint, with 36 major countries responsible for 4.4% of annual global CO_2e emissions.(1) In England, Australia and the United States (US), healthcare is responsible for 3%, 7%, and 10% of national CO_2e emissions, respectively.(1-3) This demonstrates the urgent need for rapid decarbonisation of the health sector, and the National Health Service (NHS) has led the world in this endeavour.(4) Further reductions, however, will require changes to clinical care, with much of the NHS gains to date coming from reduced reliance on coal and oil for onsite heating, and the decarbonisation of the United Kingdom (UK) electricity grid.(4) Yet, the evidence base for changes to clinical care that will reduce carbon emissions, without adversely impacting quality of care and healthcare costs, is limited. Previous studies of interventions to reduce the carbon footprint of clinical care have focused on reducing waste, recycling, and reusing equipment,(5, 6) in line with standard principles of environmental sustainability (avoid, reduce, reuse, recycle). In many clinical areas, however, reusing and recycling opportunities are limited.(7) The opportunity to reduce emissions through avoidance and reduction has been largely unexplored to date.

An acceleration in decreasing carbon emissions could be achieved by reducing low value care, which is estimated to comprise around 30% of all healthcare.(8) Unnecessary testing, a significant contributor to low value care, can lead to a cascade of additional unneeded testing, overdiagnosis, and potentially harmful overtreatment.(9, 10) Unnecessary testing may therefore lead to patient harms, financial costs to individuals and the community, and preventable carbon emissions. In other sectors of the economy, the triple bottom line has been used for over two decades as a sustainability framework to examine a product or company's impact in three domains – social, economic, and environmental.(11) The triple bottom line was intended to examine a company's activity in a way that thoroughly measured its "costs" of doing business. This framework has been little considered in healthcare, and not beyond specific policy and planning applications.(12) Yet, it could easily be adapted to consider the health, economic and environmental impacts of clinical care. As in business, it could be used to make explicit the true "costs" of healthcare, including unnecessary testing.

Vitamin D testing may be an exemplar of an opportunity to reduce the carbon footprint of healthcare associated with low value care. Most medical authorities, including the US Preventive Services Task Force,(13) National Institute for Health and Care Excellence,(14) and the Royal College of Pathologists of Australasia,(15) do not recommend vitamin D deficiency screening. Nevertheless, vitamin D testing rates are high and have been increasing in recent years across multiple countries, including in the UK, where there has been a tenfold increase in vitamin D testing since 2001.(16) A Swiss study found that vitamin D levels were tested in 14% of a large nationally representative sample in 2015 and 20% in 2018, with the increase in testing occurring both in all age groups and low-risk patients (among whom testing was likely unnecessary).(17) In Australia, persistent rises in vitamin D testing rates between 2000 and 2013 led to the introduction of new criteria for financial rebates via the universal insurer, the Medicare Benefits Schedule (MBS), in November 2014. The new criteria were intended to discourage testing in low-risk people while still allowing testing in those at particular risk of vitamin D deficiency.(18) Whilst initially successful (2014-2016 rates were 47% lower compared with 2013-2014 rates), testing rates have again risen in more recent years (by 34% between 2015 and 2019).(18)

Our aim in this study was to estimate the health, financial and environmental impacts of unnecessary vitamin D testing as a demonstration case of the use of the triple bottom line approach to make explicit the full costs to the community of this example of low value care.

Methods:

Overview:

Our triple bottom line approach involved estimating the health, financial and environmental impacts of unnecessary vitamin D testing. Our measure of health impact was the annual number of unnecessary vitamin D tests (delivering zero health gain to patients, in contrast to necessary testing which could improve health); our measure of financial impact was the annual cost of these tests in $AUD to Medicare (the Australian government universal insurer); and our measure of the environmental impact was the annual carbon emissions in kg CO_2e (also expressed as km driven in a standard passenger car). For context, we calculated the total financial cost and carbon emissions of all vitamin D tests.

Patient and Public Involvement:

No patients were involved in this study.

Estimating unnecessary tests

To estimate the *proportion (percentage)* of vitamin D tests that may be considered unnecessary, we conducted a rapid evidence review of peer-reviewed literature estimating the proportion of unnecessary vitamin D tests ordered (see Table 1 for definitions of unnecessary testing). We searched the following databases: Scopus, ScienceDirect, PubMed and Google Scholar. We used the following search terms: 'vitamin d test*' OR 'vit d test*' OR 'pathology test' OR 'vitamin d screening' OR 'vit d screening' OR 'vitamin d deficien*' OR 'vit d deficien*' AND 'unnecessary' OR 'unneeded' OR 'avoidable' OR 'avoid' OR 'excess' OR 'inessential' OR 'useless' OR 'worthless' OR 'irrelevant' OR 'reduce' OR 'too much'.

Papers were considered if peer-reviewed and published in the past ten years (between January 2011–2021). We included both international and country-specific papers published in English. We firstly screened titles and abstracts, and articles were then evaluated in full to ensure relevance to our focus of unnecessary vitamin D testing or screening. This search was complemented with forwards and backwards citation searches of included articles.

To estimate the *number of vitamin D tests* in Australia considered unnecessary, we applied the percentage most applicable to the current Australian population and context, identified in our literature review to the absolute number of vitamin D tests conducted in Australia in 2020.

Calculating financial costs

We calculated the total cost to the Australian government, based on Medicare rebates of the vitamin D tests under the MBS (Medicare Benefits Scheme). These rebate amounts are set by the Australian Government as costs paid to providers for medical services.(19) We obtained publicly available costs data for all vitamin D testing (MBS item numbers 66833, 66834, 66835, 66836, and 66837) (the different item numbers are for billing by different providers, a general practitioner or a specialist, and whether or not the test is done as part of managing treatment of related conditions such as hyperparathyroidism or hypercalcaemia).(20)

Calculating the environmental impact

To calculate the *carbon footprint of vitamin D testing* in Australia, we used data from our previous study of the carbon footprint of common pathology tests.(7) We distinguished between tests ordered as the primary test and those ordered as an add on to other test. The marginal carbon footprint of add on tests is less than tests ordered as the primary test; for example, the carbon footprint for a primary vitamin D test is 99g CO_2e, and for an add on test it is 0.5g CO_2e.(7) We conducted base case and sensitivity analyses. The base case and sensitivity analyses assumed 8% and 12% respectively of vitamin D tests were ordered as the primary reason for the blood test, from reasons reported for vitamin D test ordering in Australian general practice.(21) We present the results in kg CO_2e and as kilometres driven in an Australian standard passenger car.(22)

Determining vitamin D testing rates

To determine the number of vitamin D tests ordered in Australia, we obtained Medicare Item Reports for current vitamin D pathology services for 25-hydroxyvitamin D or 1,25-dihydroxyvitamin D quantification in serum (MBS item numbers 66833, 66834, 66835, 66836, and 66837).(23)

We obtained the total testing count and per capita rates for each item number from November 2014 (when the current items were first introduced) until December 2020. We averaged the monthly data from 2018 and 2019, and compared these averages to the 2020 data, both nationally and across all Australian states and territories.

Results

Unnecessary testing

We identified eight studies that estimated the proportion (%) of vitamin D tests that are unnecessary. These studies and their results are summarised in Table 1, and a more detailed table is included in supplementary material (Appendix 1). The proportion of tests considered unnecessary varied between 36.2% (in the UK) and 92.0% (in Canada),(24, 25) depending on the way "unnecessary testing" was defined and operationalised and on the context (country and clinical setting). For example, a 2017 study in the UK found that 70.4% to 77.5% of vitamin D tests were potentially inappropriate, depending on whether or not falls and osteoporosis were justified as appropriate reasons for testing.(26) Another more recent UK study reported a 36.2% reduction in the number of vitamin D tests ordered following the introduction of an electronic laboratory request form, an intervention to reduce the number of unnecessary tests, indicating that at least 36.2% of the tests ordered pre-implementation were likely unnecessary.(24)

Only one study quantified the number of unnecessary tests in Australia.(27) This study looked at whether the changes introduced in 2013 to restrict rebates for vitamin D testing to a set of relevant clinical indications had resulted in less unnecessary testing. It found that 76.5% of vitamin D tests conducted in 2016 had none of the clinical indications for the test, based on information extracted from individual patient records, and were thus considered unnecessary. This was an unexpected increase from 71.3% in 2013 before the restrictions had been implemented but was consistent with vitamin D testing rates which, following an initial drop, had returned to 2013 levels and then continued to grow.

Table 1: Studies reporting on the number of unnecessary vitamin D tests ordered in primary care

Study authors, year	Study title	Country	Unnecessary tests %	Definition for unnecessary
Gonzalez-Chica & Stocks (2019) (27)	Changes to the frequency and appropriateness of vitamin D testing after the introduction of new Medicare criteria for rebates in Australian general practice: evidence from 1.5 million patients in the NPS Medicine Insight database	Australia	76.5%	Tests not meeting the new MBS criteria
Woodford et al., 2018 (26)	Vitamin D: too much testing and treating?	UK	70.4-77.5%	Indication of test (known appropriateness, uncertain, not clearly justified).
Patel et al., 2020 (24)	Reducing vitamin D requests in a primary care cohort: a quality improvement study	UK	36.2%	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Ferrari & Prosser, 2016 (25)	Testing Vitamin D Levels and Choosing Wisely	Canada	92.0%	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Naugler et al., 2017 (28)	Implementation of an intervention to reduce population-based screening for vitamin D deficiency: a cross-sectional study	Canada	91.4%	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Rodd et al., 2018 (29)	Increased rates of 25-hydroxy vitamin D testing: Dissecting a modern epidemic	Canada	65.2%	Whether patient had apparent reason for test (followed consensus guidelines and clinical expertise to define what is appropriate)
Felcher et al., 2017 (30)	Decrease in unnecessary vitamin D testing using clinical decision support tools: making it harder to do the wrong thing	US	43.8%	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Petrilli et al., 2018 (31)	Reducing Unnecessary Vitamin D Screening in an Academic Health System: What Works and When	US	37.0%	No high-risk condition identified in the year prior to test ordering

These studies display considerable heterogeneity, so we did not pool the results. We used the Australian estimate of 76.5% of vitamin D tests being unnecessary for our analyses because of its applicability to our research question. The study was based on a large, population-based sample of 1.5 million patient records, and was undertaken recently, therefore reflecting current clinical practice.(27)

Vitamin D testing rates

A total of 4,457,657 vitamin D tests were done in 2020, an 11.8% increase from the average annual rate in 2018 and 2019 (3,987,644 tests) (Figure 1).

During 2020, there were visible declines in testing that coincided with Australia's national public health "stay at home" orders in response to Covid-19 from late March until mid-May, and a further "stay at home" order in the state of Victoria in the second half of 2020 (see supplementary material, Appendix 2). Despite these impacts of the pandemic, total tests conducted in 2020 surpassed the total for previous years, and data for the first half of 2021 show a further increase in monthly testing numbers (data not shown).

Triple bottom line results

Triple bottom line results are shown in Table 2.

Health impact

Of the total 4,457,657 vitamin D tests conducted, 3,410,108 (76.5%) can be considered unnecessary and these, by definition, delivered no health benefit to patients.

Financial impact

The total cost to Medicare of unnecessary vitamin D tests in 2020 was $87,229,690. The total cost of all vitamin D tests was $114,025,739.

Environmental impact

Carbon emissions from unnecessary vitamin D tests were 28,576kg CO_2e, equivalent to driving 157,970km travelled in a standard passenger car. In the sensitivity analysis, carbon emissions from unnecessary tests 42,012kg CO_2e, equivalent to driving 232,242km. The carbon emissions from all 2020 vitamin D tests were 37,355kg CO_2e (54,918kg CO_2e in sensitivity analysis).

Table 2: Triple bottom line showing the impact of unnecessary vitamin D tests in Australia, 2020 (and of total vitamin D tests)

Health	**Cost to Medicare ($AUD)**	**Carbon footprint (kg CO_2e) Base case analysis**	**Carbon footprint (kg CO_2e) Sensitivity analysis**
Unnecessary vitamin D tests:			
3,410,108	$87,229,690	28,576kg CO_2e Equivalent to 157,970km travelled in a standard passenger car	42,012kg CO_2e Equivalent to 232,242km travelled in a standard passenger car
Total vitamin D tests:			

4,457,657	$114,025,739	37,355kg CO_2e Equivalent to 206,496km travelled in a standard passenger car	54,918kg CO_2e Equivalent to 303,584km travelled in a standard passenger car

Discussion

Statement of principal findings

Our triple bottom line assessment highlights the large number of unnecessary vitamin D tests (>3 million per year) conducted in Australia. In 2020, these unnecessary tests incurred a financial cost to the Australian government of over $87 million and a carbon burden equivalent to 28,000–42,000kg CO_2e or driving approximately 160,000-230,000km in a standard, petrol-fueled, passenger car, while delivering no health benefit. Furthermore, we found the total number of vitamin D tests (necessary and unnecessary) conducted annually in Australia is inexplicably large for a population with abundant sun exposure. In a total population of 25,694,393 people, we found there is on average one vitamin D test conducted for every six Australians per year.(32)

Strength and limitations

To our knowledge, this is the first study to undertake a triple bottom line assessment of a health intervention to explore and make explicit its health, financial and environmental impacts. This demonstration case may help to raise awareness of the opportunity to generate environmental benefits by reducing acknowledged sources of unnecessary or low value care, including overtesting and consequent overtreatment. Given that efforts to date to reduce low value care in general, and unnecessary testing specifically, have been met with only limited success, triple bottom line assessments may help by using carbon emissions reduction targets to provide additional motivation and incentive for change by underscoring the environmental co-benefits of reducing low value care. As low value care represents approximately 30% of total healthcare,(8) the potential to realise environmental co-benefits is significant.

Our estimates of the carbon emissions and costs that could be saved by eliminating unnecessary vitamin D tests are likely underestimates. Internationally, up to 92% of vitamin D tests may be unnecessary,(25) and the estimate of 76.5% for unnecessary tests in Australia was based on 2016 data.(27) Testing rates in Australia have continued to rise with likely an even higher proportion being unnecessary. Furthermore, we have included only tests rebated by Medicare, and some tests are not rebatable, including those done on individuals (non-permanent residents) who are not covered by Medicare, and tests done through some private enterprises (e.g., naturopaths). Secondly, as demonstrated by our sensitivity analysis, the carbon footprint will depend heavily on the proportion of vitamin D tests that are ordered as the principal reason for ordering a pathology test in that episode of care. While vitamin D tests are rarely ordered in isolation (we assumed only 8% were the primary reason in our base case), it is hard to judge which test motivates test ordering when vitamin D tests are co-ordered with other tests, and we found little data to guide our estimates. In our sensitivity analysis, we increased the proportion of vitamin D tests being ordered primarily for vitamin D level (rather than being an additional co-ordered test) to 12% based on reported reasons for vitamin D test ordering in Australian primary care practice.(21) However, anecdotal evidence from general practitioner colleagues suggests that these proportions may be much higher, with one reason being the sustained recent interest in vitamin D testing (and supplementation) prevalent in the professional and lay community.

Our study has limitations. Our dichotomy of unnecessary/necessary tests relies on the definitions and assessments made by study authors to underpin the estimates of unnecessary testing reported in Table 1, and there is variation internationally. However, the estimate of the proportion of unnecessary tests that we used should be highly appliable to Australia. Furthermore, we acknowledge that unnecessary tests is a surrogate measure or proxy for health impact, rather than a direct measure. We note, however, that national guidelines recommend against population testing or screening because evidence of health benefit from vitamin D testing is lacking,(13, 14) and that high quality evidence does not support an association between vitamin D supplementation and improvements in fatigue, depression, chronic pain, and osteoarthritis,(33-37) or reduce the risk of developing cancer, diabetes or bone fractures.(37) Our literature review demonstrates that there is global acceptance that unnecessary vitamin D testing occurs and is common; it seems reasonable to conclude there is no, or at most negligible, health benefit from such testing.

Our analysis is specific to Australia, and we acknowledge that internationally, the proportion of vitamin D tests that are unnecessary varies widely from 37% to 92%. Using these different proportions would result in different estimates of costs and carbon emissions in those jurisdictions. Importantly, our estimate of carbon emissions is specific to Australia, as our estimate of the carbon footprint of pathology tests was conducted in Australia,(7) and therefore is reliant on Australian energy supply and emissions from supply chains, which will be different in different countries. We note that there are environmental impacts other than carbon emissions, for example, emission of PM2.5 which contribute to air pollution, that have not been included in our analysis. While important, these other environmental impacts are beyond the scope of the present study.

Importance of our results in relation to other studies

Despite recommendations against vitamin D screening or population testing in guidelines,(13-15, 38) and by advocacy groups such as Choosing Wisely,(39-42) vitamin D testing persists. Our finding that vitamin D testing rates continued to grow over 2020 is consistent with a recent US study,(43) which found that prescriptions for vitamin D supplements increased by 9.9% over the previous year, peaking in March 2020 when the US declared a national emergency due to COVID-19. These changes could potentially be due to the high prevalence of misinformation and controversy around COVID-19 and vitamin D,(44) including misplaced beliefs that vitamin D testing and supplementation might be of benefit in preventing and treating COVID-19 despite guidance and randomised trials to the contrary.(45-48)

The financial costs of vitamin D testing are considerable to health systems. The total cost of vitamin D tests in the UK increased from £1million to £17million between 2001 and 2018, not including the indirect costs of testing and appointments paid for by individuals. In Australia, vitamin D testing was estimated to cost $1.1 million to Medicare in 2000, rising to $105 million in 2019.(18) We have demonstrated a further increase to $114 million in 2020, of which $87 million was incurred from unnecessary testing.

Implications

Our triple bottom line assessment provides compelling evidence that unnecessary vitamin D testing is common and costly in financial terms and carbon emissions while delivering no health gains for patients. This case study is just one example of low value care, and impacts would be much greater for low value care more broadly. Triple bottom line assessments like this one could provide a more comprehensive picture of the total costs to society of low value care and may help strengthen and accelerate the decarbonisation of healthcare. There may be opportunities for policy documents (e.g., guidelines) and practice initiatives (e.g., Choosing Wisely) to augment their messages with

salient information about the environmental impact of unnecessary and low value care. Triple bottom line assessments done in other jurisdictions and for other clinical care activities based on local testing rates, financial costs, and carbon emissions would be of value as each of the triple bottom line components will vary between countries, regions, and health systems.

Unanswered questions

It remains unknown and untested to date whether information about the environmental impact of unnecessary testing (in addition to information about effects on health and health sector costs) will provide additional motivation for clinicians, policymakers, and patients to reduce low value care. Furthermore, factors underlying the persistent trend towards apparently ever higher vitamin D testing in particular warrant exploration.

Conclusion

High rates of unnecessary vitamin D tests in Australia represent low-value care, wasted resources and avoidable carbon emissions for no gain in health outcomes. Reducing unnecessary health services is a cost-saving approach to decreasing the carbon footprint of healthcare and deserves additional attention in policy, practice, and future research.

Transparency declaration: the lead author (the manuscript's guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as originally planned (and, if relevant, registered) have been explained.

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Contributorship statement: AB and KB conceived the study. All authors were involved in designing the study and developing the methods. AB obtained funding. AB and KB coordinated the running of the study; MBP, KP and KB conducted the rapid evidence review; MBP conducted the data collection; MBP and AB conducted the analysis. MBP and AB drafted the manuscript. All authors critically revised the manuscript. AB and MBP are guarantors.

Data sharing statement: Extra data is available by emailing matilde.petersen@sydney.edu.au

Ethics approval statement: Ethics approval not required for this study, as human/animal participants were not involved, and we used publicly available data only.

Competing interests: None declared.

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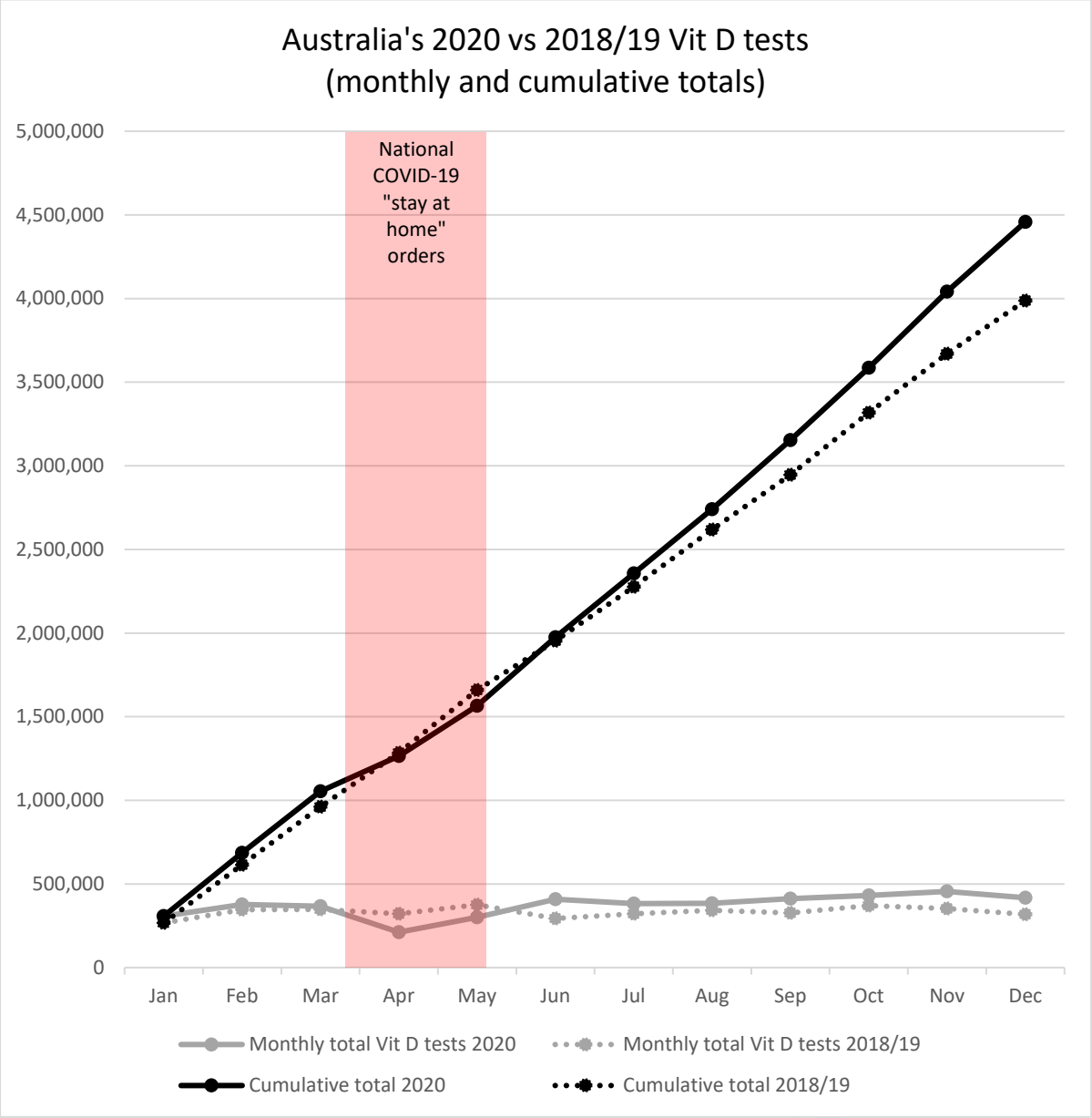
Figure 1: Australia's Vitamin D monthly and cumulative testing rates in 2020 compared with the average in 2018 and 2019



Supplementary material for submission titled: The health, financial and environmental impacts of unnecessary vitamin D testing: a triple bottom line assessment

Appendix 1

Studies reporting on the number of unnecessary vitamin D tests, detailed table and description

Study authors, year	Study title	Country	Study Type	Year of data	Unnecessary tests % (95% C.I)
Felcher et al., 2017	Decrease in unnecessary vitamin D testing using clinical decision support tools: making it harder to do the wrong thing	US	Retrospective descriptive study	2014	43.8% (N/A)
Ferrari & Prosser, 2016	Testing Vitamin D Levels and Choosing Wisely	Canada	Pre-post interventional study	2015	92.0% (N/A)
Naugler et al., 2017	Implementation of an intervention to reduce population-based screening for vitamin D deficiency: a cross-sectional study	Canada	Cross-sectional study	2015	91.4% (N/A)
Rodd et al., 2018	Increased rates of 25-hydroxy vitamin D testing: Dissecting a modern epidemic	Canada	Retrospective descriptive study	2013	65.2% (64.4-66.0)
Petrilli et al., 2018	Reducing Unnecessary Vitamin D Screening in an Academic Health System: What Works and When	US	Pre-post interventional study	2015-2016	37.0% (N/A)
Patel et al., 2020	Reducing vitamin D requests in a primary care cohort: a quality improvement study	UK	Pre-post interventional study	2016-2017	36.2% (N/A)
Woodford et al., 2018	Vitamin D: too much testing and treating?	UK	Retrospective descriptive study	2017	70.4-77.5% (N/A)
Gonzalez-Chica & Stocks (2019)	Changes to the frequency and appropriateness of vitamin D testing after the introduction of new Medicare criteria for rebates in Australian general practice: evidence from 1.5 million patients in the NPS Medicine Insight database	Australia	Dynamic cohort study	2016	76.5% (N/A)

Felcher et al. (2017) identified that 43.8% of vitamin D tests conducted prior to implementing a clinical decision support tool were inappropriate, and only 56.3% of tests were ordered for people identified as being at risk of vitamin D deficiency.

A Canadian study by Ferrari & Prosser (2016) found a 92% reduction in vitamin D tests ordered following a 9-month period of a criteria-based intervention.

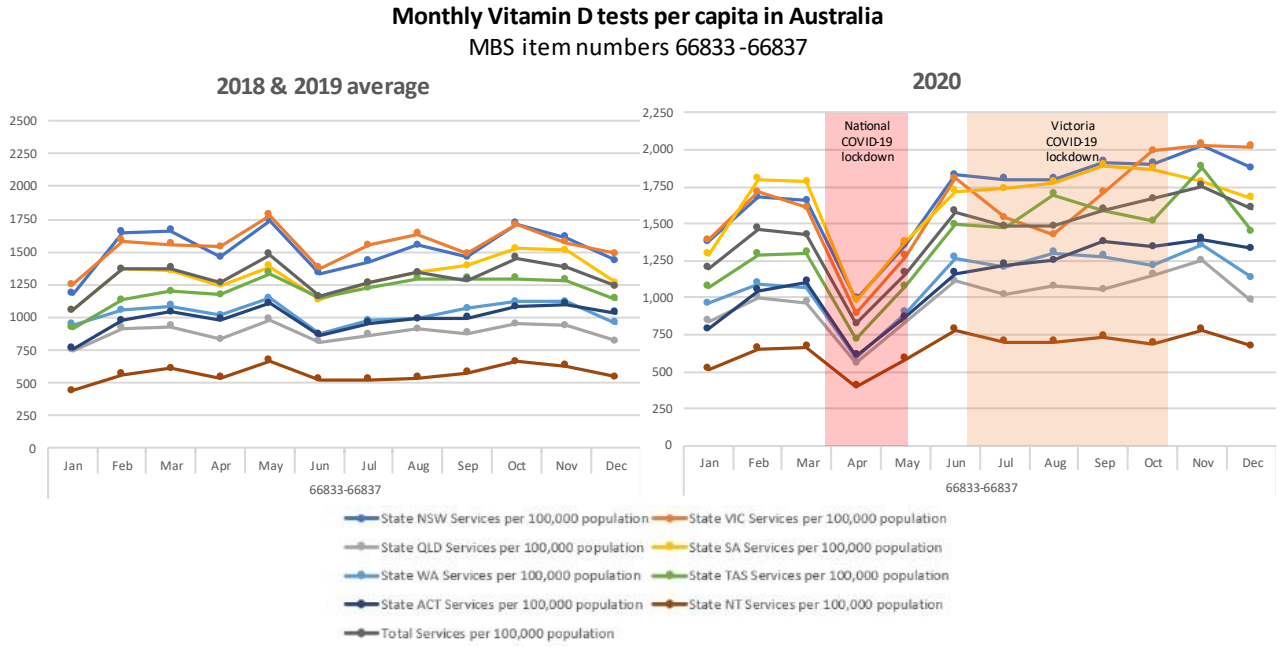
Another Canadian study (Naugler et al., 2017) implemented a specialised Choosing Wisely requisition for vitamin D ordering, which was found to result in a 91.4% reduction in vitamin D tests over 12 months.

A more recent study by Rodd et al. (2018) retrospectively examined the number of tests ordered from 2006 to 2013, and determine the proportion of tests that were inappropriate, which they defined as tests without apparent underlying problems warranting measurement. This study identified a rate of 65.2% for inappropriate tests in 2013, compared with 49.4% in 2006, demonstrating a dramatic increase of one third.

Petrilli et al. (2018) identified 37.0% of vitamin D tests as being unnecessary in the US prior to the implementation of an intervention to reduce unnecessary testing.

Appendix 2:

Figure 2: Australia's monthly vitamin D tests per capita in Australia, showing the average across 2018 and 2019, compared with 2020 testing rates.



These Victorian "stay at home" order and other public health measures lasted from late June until late October, which is reflected by a drastic drop from 1,805 tests to 1,425 tests per 100,000 population. The state testing rates per capita are compared in Figure 2, along with markers to show both the national and Victorian "stay at home" order.

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The health, financial and environmental impacts of unnecessary vitamin D testing: a triple bottom line assessment adapted for healthcare

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The health, financial and environmental impacts of unnecessary vitamin D testing: a triple bottom line assessment adapted for healthcare

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ABSTRACT

Objective: To undertake an assessment of the health, financial, and environmental impacts of a well-recognised example of low value care; inappropriate vitamin D testing.

Design: Combination of systematic literature search, analysis of routinely collected healthcare data and environmental analysis.

Setting: Australian healthcare system.

Participants: Population of Australia.

Outcome measures: We took a sustainability approach, measuring the health, financial, environmental impacts of a specific healthcare activity. Unnecessary vitamin D testing rates were estimated from best available published literature; by definition, these provide no gain in health outcomes (in contrast to appropriate/necessary tests). Australian population-based test numbers and healthcare costs were obtained from Medicare for vitamin D pathology services. Carbon emissions in kg CO_2e were estimated using data from our previous study of the carbon footprint of common pathology tests. We distinguished between tests ordered as the primary test and those ordered as an add-on to other tests, as many may be done in conjunction with other tests. We conducted base case (8% being the primary reason for the blood test) and sensitivity (12% primary test) analyses.

Results: There was a total of 4,457,657 Medicare funded vitamin D tests in 2020, on average one test for every six Australians, an 11.8% increase from the mean 2018-2019 total. From our literature review, 76.5% of Australia's vitamin D tests provide no net health benefit, equating to 3,410,108 unnecessary tests in 2020. Total costs of unnecessary tests to Medicare amounted to >$87,000,000AUD. The 2020 carbon footprint of unnecessary vitamin D tests was 28,576kg (base case) and 42,012kg (sensitivity) CO_2e, equivalent to driving ~160,000–230,000km in a standard passenger car.

Conclusions: Unnecessary vitamin D testing contributes to avoidable CO_2e emissions and healthcare costs. While the footprint of this example is relatively small, the potential to realise environmental co-benefits by reducing low value care more broadly is significant.

Strengths and limitations of this study

Strengths:

- This is the first study to undertake an adapted triple bottom line assessment of a low value healthcare activity to explore and make explicit its health, financial and environmental impacts.
- Our triple bottom line assessment of vitamin D testing highlights that low value care, which provides little or no gain in health outcomes, adds significant financial costs, and contributes avoidable CO_2e emissions.
- Reducing low value care is an opportunity to reduce carbon emissions and expenditure on healthcare without adversely affecting quality of care or patient outcomes; this is an important consideration in achieving healthcare sustainability.

Limitations of this study:

- Unnecessary tests or inappropriate testing is a surrogate measure of health impact, rather than a direct measure.
- Our estimate of carbon emissions is specific to Australia and estimates will be different in other countries depending on local electricity sources and supply chains.
- Other environmental impacts, such as emissions of PM2.5 which contribute to air pollution, have not been included in our analysis.

Introduction

Healthcare has a significant carbon footprint, with 36 major countries responsible for 4.4% of annual global CO_2e emissions.(1) In England, Australia and the United States (US), healthcare is responsible for 3%, 7%, and 10% of national CO_2e emissions, respectively.(1-3) This demonstrates the urgent need for rapid decarbonisation of the health sector, and the National Health Service (NHS) has led the world in this endeavour.(4) Further reductions, however, will require changes to clinical care, with much of the NHS gains to date coming from reduced reliance on coal and oil for onsite heating, and the decarbonisation of the United Kingdom (UK) electricity grid.(4) Yet, the evidence base for changes to clinical care that will reduce carbon emissions, without adversely impacting quality of care and healthcare costs, is limited. Previous studies of interventions to reduce the carbon footprint of clinical care have focused on reducing waste, recycling, and reusing equipment,(5, 6) in line with standard principles of environmental sustainability (avoid, reduce, reuse, recycle). In many clinical areas, however, reusing and recycling opportunities are limited.(7) The opportunity to reduce emissions through avoidance and reduction has been largely unexplored to date.

An acceleration in decreasing carbon emissions could be achieved by reducing low value care, which is estimated to comprise around 30% of all healthcare.(8) Unnecessary testing, a significant contributor to low value care, can lead to a cascade of additional unneeded testing, overdiagnosis, and potentially harmful overtreatment.(9, 10) Unnecessary testing may therefore lead to patient harms, financial costs to individuals and the community, and preventable carbon emissions.(11,12) In the business sector, the triple bottom line has been used for over two decades to go beyond simply examining profit and loss (the primary purpose of business), and make explicit and visible the full financial, environmental and social costs of an activity.(13) This sustainability framework has been little considered in healthcare,(14) and not used extensively beyond specific policy and planning applications.(15) Yet, it could easily be adapted to consider the health (as the primary purpose of healthcare), economic and environmental impacts of clinical care. As in business, it could be used to make explicit the true "costs" of healthcare, including the "true" costs to individuals and to society of unnecessary testing. For the purpose of this study's example, we opted to substitute the 'social domain' of the triple bottom line approach with a health outcome. Health encompasses physical, psychological, emotional and social elements,(16) making it a more practical concept to measure in healthcare rather than the social measure traditionally used in the business triple bottom line framework. We do acknowledge in advance, however, that our health domain only covers the clinical health outcomes for our low value healthcare example.

Vitamin D testing may be an exemplar of an opportunity to reduce the carbon footprint of healthcare associated with low value care. There is currently no sufficient evidence of health benefits and harms of testing vitamin D levels.(17-24) Vitamin D testing is indicated in individuals at particularly high risk of abnormal vitamin D levels or related complications, including patients with osteoporosis, hyperparathyroidism, malabsorption, chronic renal failure, or hypo-or-hypercalcaemia, and patients with severe lack of sun exposure or who use medications that reduce vitamin D levels.(25,26) Testing healthy individuals who are not at risk of vitamin D deficiency is not recommended as it wastes resources and can likely lead to unnecessary treatment in a significant subgroup of healthy individuals.(25) Most medical authorities, including the US Preventive Services Task Force,(27) National Institute for Health and Care Excellence,(28) and the Royal College of Pathologists of Australasia,(25) do not recommend vitamin D deficiency screening. Nevertheless, vitamin D testing rates are high and have been increasing in recent years across multiple countries, including in the UK, where there has been a tenfold increase in vitamin D testing since 2001.(29) A Swiss study found that vitamin D levels were tested in 14% of a large nationally representative sample in 2015 and 20% in 2018, with the increase in testing occurring both in all age groups and low-risk patients (among whom testing likely provided no net health benefit).(30) In Australia, persistent rises in vitamin D testing rates between 2000 and 2013 led to the introduction of new criteria for financial rebates via the universal insurer, the Medicare Benefits Schedule (MBS), in

November 2014. The new criteria were intended to discourage testing in low-risk people while still allowing testing in those at particular risk of vitamin D deficiency.(31) Whilst initially successful (2014-2016 rates were 47% lower compared with 2013-2014 rates), testing rates have again risen in more recent years (by 34% between 2015 and 2019).(31) This increase is not explained by demographic variations or changes in clinical factors, which suggests unnecessary testing and the lack of clinician support or awareness in regard to the MBS criteria.(31)

Our aim in this study was to estimate the health, financial and environmental impacts of unnecessary vitamin D testing as a demonstration case of the use of an adapted triple bottom line approach to make explicit the full costs to the community of this example of low value care.

Methods:

Overview:

While vitamin D testing provides health benefits to some patients, many studies have shown that a proportion of vitamin D tests provide no health benefit (see below). We used the logic of the triple bottom line approach to estimate the financial and environmental impacts of these vitamin D tests of no net health value; that is, the size of our health outcome was set to zero. As such, our measure of health impact was the annual number of 'unnecessary' vitamin D tests (delivering zero health gain to patients) conducted in Australia in 2020; our measure of financial impact was the annual cost of these tests in $AUD to Medicare (the Australian government universal insurer); and our measure of the environmental impact was the annual carbon emissions in kg CO_2e (also expressed as km driven in a standard passenger car). For context, we calculated the total financial cost and carbon emissions of all vitamin D tests in Australia in 2020.

Patient and Public Involvement:

No patients were involved in this study.

Health impact (Zero): Estimating the proportion and number of vitamin D tests with no net health benefit (unnecessary tests)

To estimate the *proportion (percentage)* of vitamin D tests that provide no net health benefit, we conducted a rapid evidence review of peer-reviewed studies which provided an estimate of the proportion of inappropriate or unnecessary vitamin D tests (see Table 1 for how this was defined by each study). We searched the following databases: Scopus, ScienceDirect, and PubMed. We used the following search terms: 'vitamin d test*' OR 'vit d test*' OR 'pathology test' OR 'vitamin d screening' OR 'vit d screening' OR 'vitamin d deficien*' OR 'vit d deficien*' AND 'unnecessary' OR 'unneeded' OR 'avoidable' OR 'avoid' OR 'excess' OR 'inessential' OR 'reduce' OR 'too much'.

Papers were considered if peer-reviewed, and published in the past ten years (between January 2011–2021). We included both international and country-specific papers published in English. We firstly screened titles and abstracts, and articles were then evaluated in full to ensure relevance to our focus of estimating the proportion of inappropriate/unnecessary vitamin D testing in community (primary care) settings. This search was complemented with forwards and backwards citation searches of included articles (see Supplementary Figure 1, for complete search results displayed in a PRISMA flow diagram).

Results were heterogeneous so we did not pool them in meta-analysis. Instead we used the best, most applicable (to the Australian population and context) estimate and applied this proportion to the absolute number of vitamin D tests conducted in Australia in 2020 (see below).

Determining vitamin D test numbers

To determine the number of vitamin D tests ordered in Australia, we obtained Medicare Item Reports for current vitamin D pathology services for 25-hydroxyvitamin D or 1,25-dihydroxyvitamin D quantification in serum (MBS item numbers 66833, 66834, 66835, 66836, and 66837).(32)

We obtained the total testing counts and rates (per 100,000 population) for each item number from November 2014 (when the current items were first introduced) until December 2020. We averaged the monthly data from 2018 and 2019, and compared these averages to the 2020 data, both nationally and across all Australian states and territories.

Financial impact

We calculated the total 2019 and 2020 financial cost to the Australian Government, based on Medicare rebates of the vitamin D tests under the MBS (Medicare Benefits Scheme). These rebate amounts are set by the Australian Government as costs paid to providers for medical services.(33) We obtained publicly available costs data for all vitamin D testing (MBS item numbers 66833, 66834, 66835, 66836, and 66837) (the different item numbers are for billing by different providers, a general practitioner or a specialist, and whether or not the test is done as part of managing treatment of related conditions such as hyperparathyroidism or hypercalcaemia).(34)

Environmental impact

To calculate the *carbon footprint of vitamin D testing* in Australia, we used data from our previous study of the carbon footprint of common pathology tests.(7) The emissions measured were solely the carbon arising from the plastic and electricity required to run vitamin D tests. We did not include all the compounding 'cascade' impacts that flow from performing a vitamin D test providing no net health benefit,(35) such as buying vitamin D supplements, additional bone scans, and coming back for repeat vitamin D testing.

We distinguished between tests ordered as the primary test and those ordered as an add on to another test, as vitamin D is often requested as an "add on" test. The marginal carbon footprint of add on tests is less than tests ordered as the primary test; for example, the carbon footprint for a primary vitamin D test is 99g CO_2e, but when performed as an add on test is 0.5g CO_2e.(7) We conducted base case and sensitivity analyses of 2020 data. The base case and sensitivity analyses assumed 8% and 12% respectively of vitamin D tests were ordered as the primary reason for the blood test, from reasons reported for vitamin D test ordering in Australian general practice.(36) We also conducted a second analysis using 2019 data to allow for the possibility that the appropriateness of vitamin D testing may have been affected by the COVID-19 pandemic. We present the results in kg CO_2e and as kilometres driven in an Australian standard passenger car.(37)

Results

Proportion of the vitamin D tests which provide no net health benefit (unnecessary tests)

We identified eight studies that estimated the proportion (%) of vitamin D tests that are unnecessary or inappropriate. These studies, their definitions of unnecessary or inappropriate testing, and their results are summarised in Table 1. The proportion of tests considered unnecessary varied between 36.2% (in the UK) and 92.0% (in Canada),(17, 18) depending on the way "unnecessary testing" was defined and operationalised and on the context (country and clinical setting). For example, a 2017 study in the UK found that 70.4% to 77.5% of vitamin D tests were potentially inappropriate, depending on whether or not falls and osteoporosis were justified as appropriate reasons for testing.(19) Another more recent UK study reported a 36.2% reduction in the number of vitamin D tests ordered following the introduction of an electronic laboratory request form, an intervention to reduce the number of unnecessary tests, indicating that at least 36.2% of the tests ordered pre-implementation were likely unnecessary.(17)

Only one study quantified the number of vitamin D tests providing no net health benefit in Australia.(20) This study looked at whether the changes introduced in 2013 to restrict rebates for vitamin D testing to a set of relevant clinical indications had resulted in less unnecessary testing. Their robust methodology involved comparing the vitamin D test results from the NPS Medicine

Wise Insights database for a large, representative sample of more than 1.5 million patients and patients' clinical data from the same database against the revised Medicare indications. They used a computer algorithm to do this comparison to determine the percentage that was performed with no medical indication for being done (i.e., they were unnecessary with net zero health benefit). The study found that 76.5% of vitamin D tests conducted in 2016 met none of the clinical indications for the test. This was an unexpected increase from 71.3% in 2013 before the restrictions had been implemented, but was consistent with vitamin D testing rates which, following an initial drop, had returned to 2013 levels and then continued to grow. These studies displayed considerable heterogeneity, so we did not pool the results. Instead, we used the Australian estimate of 76.5% of vitamin D tests providing no net health benefit for our analyses.(20) Due to its strong methodology, its applicability to our research question, and because it is a recent and local (Australian-based) estimate, we have confidence that the estimate of 76.5% net zero health benefit is valid and appropriate for our Australian study and reflects current clinical practice.

Table 1: Studies reporting on the number of unnecessary vitamin D tests ordered in primary care

Study authors, year	Study title	Country	Study Type	Year of data collection	Unnecessary tests % (95% C.I.)	Definition for unnecessary/providing no net health benefit
Gonzalez-Chica & Stocks (2019) (20)	Changes to the frequency and appropriateness of vitamin D testing after the introduction of new Medicare criteria for rebates in Australian general practice: evidence from 1.5 million patients in the NPS Medicine Insight database	Australia	Dynamic cohort study	2016	76.5% (N/A)	Tests not meeting any of the new MBS criteria
Woodford et al., 2018 (19)	Vitamin D: too much testing and treating?	UK	Retrospective descriptive study	2017	70.4-77.5% (N/A)	Indication of test (known appropriateness, uncertain, not clearly justified).
Patel et al., 2020 (17)	Reducing vitamin D requests in a primary care cohort: a quality improvement study	UK	Pre-post interventional study	2016-2017	36.2% (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Ferrari & Prosser, 2016 (18)	Testing Vitamin D Levels and Choosing Wisely	Canada	Pre-post interventional study	2015	92.0% (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Naugler et al., 2017 (21)	Implementation of an intervention to reduce population-	Canada	Cross-sectional study	2015	91.4% (N/A)	The reduction in tests ordered following an intervention to reduce

	based screening for vitamin D deficiency: a cross-sectional study					inappropriate test ordering
Rodd et al., 2018 (22)	Increased rates of 25-hydroxy vitamin D testing: Dissecting a modern epidemic	Canada	Retrospective descriptive study	2013	65.2% (64.4-66.0)	Whether patient had apparent reason for test (followed consensus guidelines and clinical expertise to define what is appropriate)
Felcher et al., 2017 (23)	Decrease in unnecessary vitamin D testing using clinical decision support tools: making it harder to do the wrong thing	US	Retrospective descriptive study	2014	43.8% (N/A)	The reduction in tests ordered following an intervention to reduce inappropriate test ordering
Petrilli et al., 2018 (24)	Reducing Unnecessary Vitamin D Screening in an Academic Health System: What Works and When	US	Pre-post interventional study	2015-2016	37.0% (N/A)	No high-risk condition identified in the year prior to test ordering

Vitamin D test numbers

A total of 4,457,657 vitamin D tests were done in 2020, an 11.8% increase from the average annual rate in 2018 and 2019 (3,987,644 tests) (Figure 1).

During 2020, there were visible declines in testing that coincided with Australia's national public health "stay at home" orders in response to Covid-19 from late March until mid-May, and a further "stay at home" order in the state of Victoria in the second half of 2020 (see Supplementary Figure 2). Despite these impacts of the pandemic, total tests conducted in 2020 surpassed the total for previous years, and data for the first half of 2021 show a further increase in monthly testing numbers (data not shown).

Triple bottom line results

Triple bottom line results are shown in Table 2.

Health impact; zero net health benefit

Of the total 4,457,657 vitamin D tests conducted, 3,410,108 (76.5%) delivered no health benefit to patients.

Financial impact

In 2020, the total cost to Medicare of vitamin D tests providing no net health benefit was $87,229,690, and the cost of all vitamin D tests combined was $114,025,739. In 2019, these financial costs were $79,909,161 for vitamin tests providing no net health benefit, and $104,456,420 for all vitamin D tests combined.

Environmental impact

Carbon emissions from vitamin D tests providing no net health benefit were 28,576kg CO_2e, equivalent to driving from Sydney (SYD) to Perth (PER) 40 times (157,970km travelled in a standard passenger car). In the sensitivity analysis, carbon emissions from unnecessary tests 42,012kg CO_2e, equivalent to driving SYD-PER 59 times (232,242km travelled in a standard passenger car). The carbon emissions from all 2020 vitamin D tests were 37,355kg CO_2e (54,918kg CO_2e in sensitivity analysis).

The results of the secondary analysis using 2019 testing data were 26,172kg CO_2e (base case analysis) and 38,477kg CO_2e (sensitivity analysis).

Table 2: Triple bottom line showing the impact of vitamin D tests providing no net health benefit in Australia, 2020 (and of total vitamin D tests)

Health impact (Zero)	**Financial impact Cost to Medicare ($AUD)**	**Environmental impact Carbon footprint (kg CO_2e) Base case analysis (8% ordered as primary test, 92% add on test)**	**Environmental impact Carbon footprint (kg CO_2e) Sensitivity analysis (12% ordered as primary test, 88% add on test)**
Vitamin D tests providing no net health benefit:			
3,410,108	$87,229,690	28,576kg CO_2e Equivalent to driving SYD-PER 40 times (157,970km travelled in a standard passenger car)	42,012kg CO_2e Equivalent to driving SYD-PER 59 times (232,242km travelled in a standard passenger car)
Total vitamin D tests:			
4,457,657	$114,025,739	37,355kg CO_2e Equivalent to driving SYD-PER 52.5 times (206,496km travelled in a standard passenger car)	54,918kg CO_2e Equivalent to driving SYD-PER 77 times (303,584km travelled in a standard passenger car)

Discussion

Statement of principal findings

Our triple bottom line assessment highlights the large number of vitamin D tests providing no net health benefit (>3 million per year) conducted in Australia. In 2020, these unnecessary tests incurred a financial cost to the Australian Government of over $87 million and a carbon burden equivalent to 28,000–42,000kg CO_2e or driving approximately 160,000-230,000km in a standard, petrol-fueled, passenger car, while delivering no health benefit. The results of our second analysis using 2019 data followed the same pattern, showing that using pre-pandemic data makes no difference to the overall picture of the true costs of these unnecessary tests. Furthermore, we found the total number of vitamin D tests (necessary and unnecessary) conducted annually in Australia is inexplicably large for a population with abundant sun exposure. In a total population of 25,694,393 people, we found there is on average one vitamin D test conducted for every six Australians per year.(38)

Strength and limitations

To our knowledge, this is one of the first studies to undertake an adapted triple bottom line assessment of a health intervention to explore and make explicit its health, financial and environmental impacts,(14) and the first to use this approach in the context of a low value care example. This demonstration case may help to raise awareness of the opportunity to generate environmental benefits by reducing acknowledged sources of unnecessary or low value care, including overtesting and consequent overtreatment. Given that efforts to date to reduce low value care in general, and unnecessary testing specifically, have been met with only limited success, triple bottom line assessments may help by using carbon emissions reduction targets to provide additional motivation and incentive for change by underscoring the environmental co-benefits of reducing low value care. As low value care represents approximately 30% of total healthcare,(8) the potential to realise environmental co-benefits is significant.

Our estimates of the carbon emissions and costs that could be saved by eliminating unnecessary vitamin D tests are likely underestimates. Internationally, up to 92% of vitamin D tests may be providing no net health benefit,(18) and the estimate of 76.5% for unnecessary vitamin D tests in Australia was based on 2016 data.(20) Testing rates in Australia have continued to rise, with likely an even higher proportion providing no net health benefit. Furthermore, we have included only tests rebated by Medicare, and some tests are not rebatable, including those done on individuals (non-permanent residents) who are not covered by Medicare, and tests done through some private enterprises (e.g., naturopaths). Secondly, as demonstrated by our sensitivity analysis, the carbon footprint will depend heavily on the proportion of vitamin D tests that are ordered as the principal reason for ordering a pathology test in that episode of care. While vitamin D tests are rarely ordered in isolation (we assumed only 8% were the primary reason in our base case), it is hard to judge which test motivates test ordering when vitamin D tests are co-ordered with other tests, and we found little data to guide our estimates. In our sensitivity analysis, we increased the proportion of vitamin D tests being ordered primarily for vitamin D level (rather than being an additional co-ordered test) to 12% based on reported reasons for vitamin D test ordering in Australian primary care practice.(36) However, anecdotal evidence from general practitioner colleagues suggests that these proportions may be much higher, with one reason being the sustained recent interest in vitamin D testing (and supplementation) prevalent in the professional and lay community.

Our study has limitations. Our dichotomy of unnecessary/necessary tests relies on the definitions and assessments made by study authors to underpin the estimates of unnecessary testing reported in Table 1, and there is variation internationally from 36% to 92% of vitamin D tests being unnecessary or inappropriate. However, the estimate of the proportion of unnecessary tests that we used is based on a high quality study and is directly applicable to our study context. Our literature review demonstrates that there is a global acceptance that unnecessary vitamin D testing occurs and is common; it seems reasonable to conclude there is no net health benefit from these unnecessary vitamin D tests. We acknowledge also that our measure of health impact focuses on the clinical

effectiveness and physical health, and omits other aspects of health, (i.e., social, psychological, and emotional health).(16) Thus, we recommend that future research adapting the triple bottom line approach in healthcare should endeavour to further broaden the social/health domain. Furthermore, we acknowledge that unnecessary tests is a surrogate measure or proxy for health impact, rather than a direct measure. We note, however, that national guidelines recommend against population testing or screening because evidence of health benefit from vitamin D testing is lacking,(27, 28) and that high quality evidence does not support an association between vitamin D supplementation and improvements in fatigue, depression, chronic pain, and osteoarthritis,(39-43) or reductions in the risk of developing cancer, diabetes or bone fractures.(43)

Our analysis is specific to Australia. Using proportions of vitamin D tests that are unnecessary in other jurisdictions would result in different estimates of costs and carbon emissions in those jurisdictions. Importantly, our estimate of carbon emissions is specific to Australia, as our estimate of the carbon footprint of pathology tests was conducted in Australia,(7) and therefore is reliant on Australian electricity supply and on emissions of medical products used in Australia, which will be different in different countries. We note that there are additional, unmeasured environmental impacts arising from testing, such as clinical waste and air and water pollution. While important, these are beyond the scope of the present study.

Importance of our results in relation to other studies

Despite recommendations against vitamin D screening or population testing in guidelines,(25, 27, 28, 44) and by advocacy groups such as Choosing Wisely,(26, 45-47) vitamin D testing at high rates persists. Our finding that vitamin D testing rates continued to grow over 2020 is consistent with a recent US study,(48) which found that prescriptions for vitamin D supplements increased by 9.9% over the previous year, peaking in March 2020 when the US declared a national emergency due to COVID-19. These changes could potentially be due to the high prevalence of misinformation and controversy around COVID-19 and vitamin D,(49) including misplaced beliefs that vitamin D testing and supplementation might be of benefit in preventing and treating COVID-19 despite guidance and randomised trials to the contrary.(50-54)

The financial costs of vitamin D testing are considerable to health systems. The total cost of vitamin D tests in the UK increased from £1million to £17million between 2001 and 2018, not including the indirect costs of testing and appointments paid for by individuals. In Australia, vitamin D testing was estimated to cost $1.1 million to Medicare in 2000, rising to $105 million in 2019.(31) We have demonstrated a further increase to $114 million in 2020, of which $87 million was incurred from testing providing no net health benefit.

Implications

Our adapted triple bottom line assessment provides compelling evidence that unnecessary vitamin D testing is common and costly in financial terms and carbon emissions while delivering no health gains for patients. This case study is just one example of low value care, and impacts would be much greater for low value care more broadly. Triple bottom line assessments like this one could provide a more comprehensive picture of the total costs to society of low value care and may help strengthen and accelerate the decarbonisation of healthcare. There may be opportunities for policy documents (e.g., guidelines) and practice initiatives (e.g., Choosing Wisely) to augment their messages with salient information about the environmental impact of unnecessary and low value care. Triple bottom line assessments done in other jurisdictions and for other clinical care activities based on

local testing rates, financial costs, and carbon emissions would be of value as each of the triple bottom line components will vary between countries, regions, and health systems.

Unanswered questions

It remains unknown and untested to date whether information about the environmental impact of unnecessary testing (in addition to information about effects on health and health sector costs) will provide additional motivation for clinicians, policymakers, and patients to reduce low value care. Furthermore, factors underlying the persistent trend towards apparently ever higher vitamin D testing in particular warrant exploration.

Conclusion

High rates of unnecessary vitamin D tests in Australia represent low-value care, wasted resources and avoidable carbon emissions for no gain in health outcomes. Reducing unnecessary health services is a cost-saving approach to decreasing the carbon footprint of healthcare and deserves additional attention in policy, practice, and future research.

Transparency declaration: the lead author (the manuscript's guarantor) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as originally planned (and, if relevant, registered) have been explained.

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Contributorship statement: AB and KB conceived the study. MBP, AB, KB, FM, KP, and SM were all involved in designing the study and developing the methods. AB obtained funding. AB and KB coordinated the running of the study; MBP, KP and KB conducted the rapid evidence review; MBP conducted the data collection; MBP and AB conducted the analysis. MBP and AB drafted the manuscript. All authors (MBP, AB, KB, FM, KP, SM) critically revised the manuscript. AB and MBP are guarantors.

Data sharing statement: Extra data is available by emailing matilde.petersen@sydney.edu.au

Ethics approval statement: Ethics approval not required for this study, as human/animal participants were not involved, and we used publicly available data only.

Competing interests: None declared.

Figure captions:

Main text - **Figure 1: Australia's Vitamin D monthly* and cumulative test numbers in 2020 compared with 2018/ 2019 averages** (corresponding footnote: **For more detail, please view Supplementary Figure 2, showing Australia's monthly vitamin D test rates.*)

Supplementary material - **Figure 1: PRISMA flow diagram of included studies; Figure 2: Monthly vitamin D test rates per 100,000 population for all Australian States and Territories in 2018/2019 and 2020 (MBS item numbers 66833-66837**).

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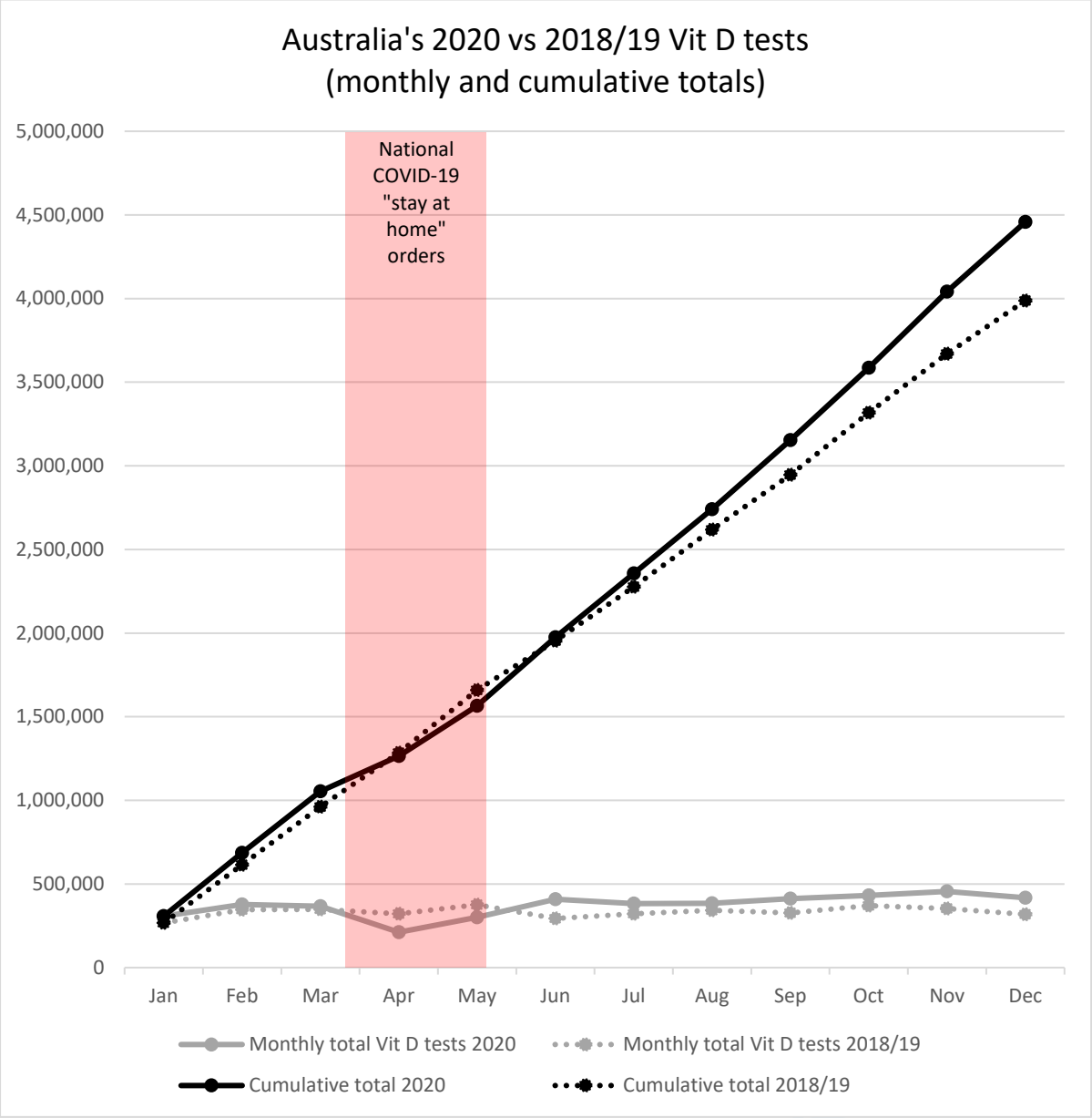
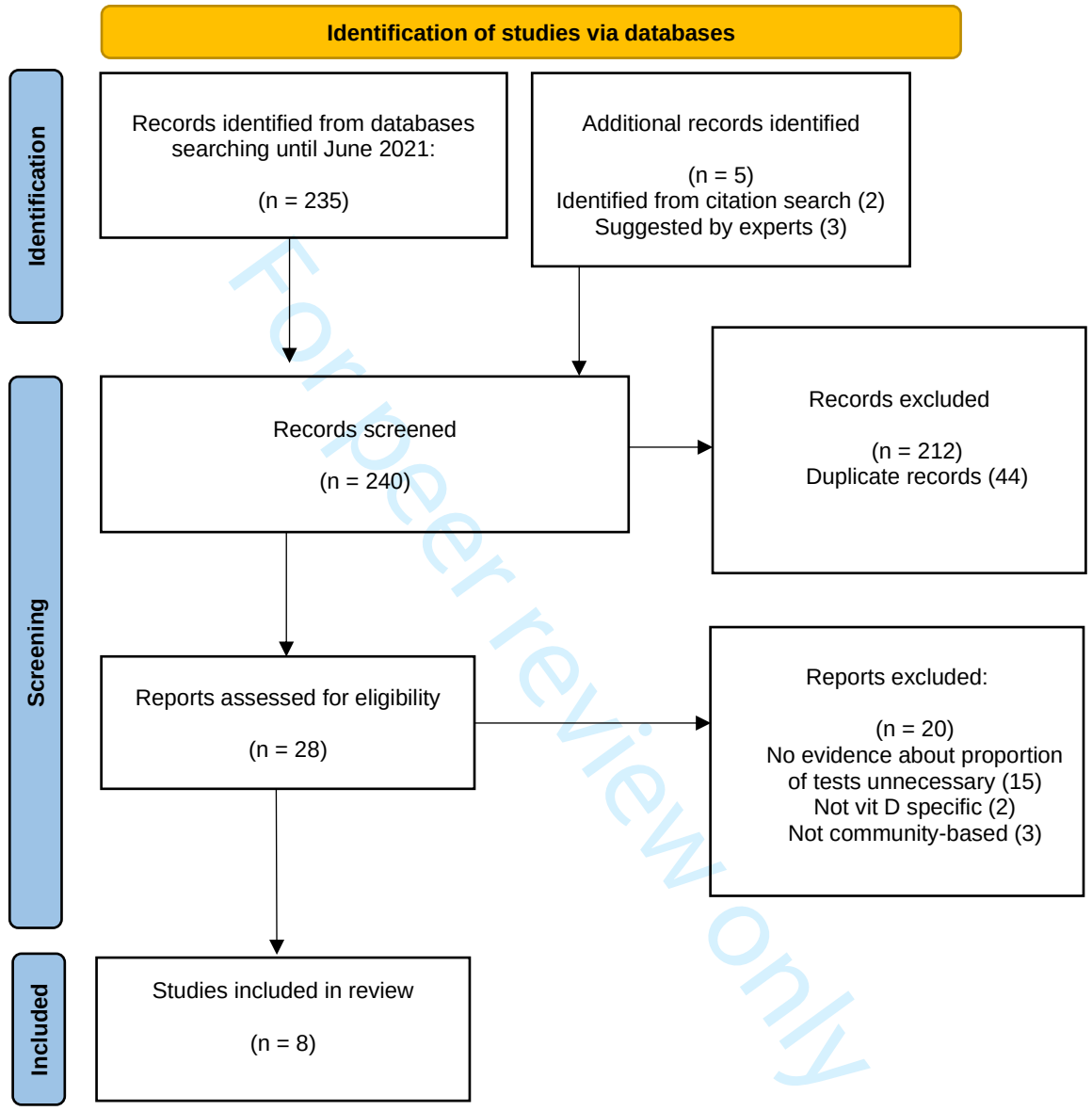
Figure 1: Australia's Vitamin D monthly* and cumulative test numbers in 2020 compared with 2018/ 2019 averages



*For more detail, please view Supplementary Figure 2, showing Australia's monthly vitamin D test rates.

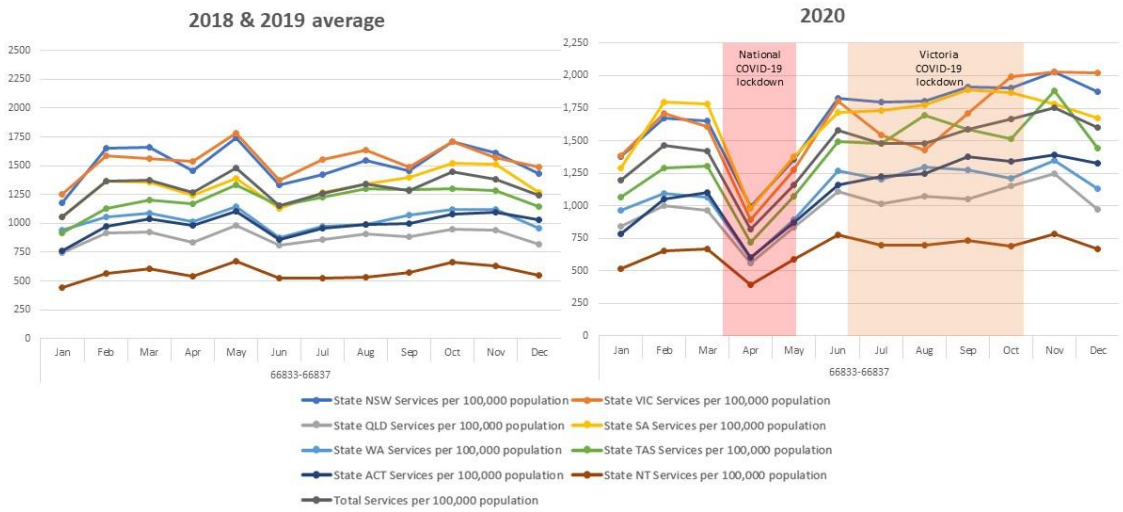
Supplementary material for submission titled: The health, financial and environmental impacts of unnecessary vitamin D testing: a triple bottom line assessment adapted for healthcare

Figure 1: PRISMA flow diagram of included studies



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Figure 2: Monthly vitamin D test rates per 100,000 population for all Australian States and Territories in 2018/2019 and 2020 (MBS item numbers 66833-66837).



The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Page 1-2 Page 6-7
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4		
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5		
Methods					
Study Design	4	Present key elements of study design early in the paper	Page 5		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 5-6		

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case	Page 6	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	Page 6-7	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 6-7		

Bias	9	Describe any efforts to address potential sources of bias			
Study size	10	Explain how the study size was arrived at	N/A		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	Page 6-7		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses	Page 6-7		
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	

				RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram	N/A	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)	N/A		
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time	N/A		

		Case-control study - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Page 9-10		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	Page 10		
Discussion					
Key results	18	Summarise key results with reference to study objectives	Page 11		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 11-12	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as	

				they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 11-13		
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 12-13		
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 14		
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.